Appendix I
USACE Hydraulic Analysis

APPENDIX I

Hydraulic Analysis

Chatfield Reservoir
Storage Reallocation Study

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**US Army Corps
of Engineers**
Omaha District

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Appendices

1. INTRODUCTION

This analysis was prepared by the U.S. Army Corps of Engineers – Omaha District, for the Tri-Lakes Reallocation Study. The purpose of this analysis is to develop water surface profiles to be used in the evaluation of alternatives prepared to optimize the utilization of the three reservoirs. Should any of the proposed alternatives negatively impact flood event water surface profiles then measures would be developed to mitigate these impacts.

The basis for the information used in this analysis was a HEC-RAS hydraulic model of the South Platte River from the Chatfield Reservoir to the Colorado-Nebraska State line, Cherry Creek from the Cherry Creek Reservoir to the confluence with the South Platte River and Bear Creek from the Bear Creek Reservoir to the confluence with the South Platte River. The basic assumptions and methodologies used in the development of these profiles have been summarized in the following text.

2. STREAM AND VALLEY CHARACTERISTICS

The South Platte River flows in a generally northerly and easterly direction through the study reach, from the Chatfield Reservoir on the west to the Colorado-Nebraska State line on the east. The South Platte River has a well defined channel downstream of Chatfield Reservoir through the Denver metropolitan area then as it flows out into the undeveloped areas it becomes braided and located in a wide shallow valley flanked by rolling plains. Slopes average approximately 7 to 8 feet per mile within the study area. Land use within the floodplain is highly urbanized from the Chatfield Reservoir downstream to the Adams-Weld County line then becomes predominantly agricultural, with the exception of development around incorporated areas, downstream of this point to the Colorado-Nebraska State line.

Cherry Creek flows in a generally westerly direction and Bear Creek in an easterly direction from their respective reservoirs through a well defined channel in an urban setting until their confluence with the South Platte River.

3. SURVEY DATA.

Survey information and cross section data, used in the development of the hydraulic model, for the reach from the Adams/Weld County line to the Colorado/Nebraska State line was provided by Kucera West through a contract with the Colorado Water Conservation Board. The basis for the survey was a 1998 aerial photogrammetry survey with the horizontal control being Colorado State Plane Coordinate System North Zone 1983 NAD and the vertical control being NGVD 1929 Sea Level Datum. The vertical data was then manually adjusted to convert the elevations to 1988 NAVD Sea Level Datum. The accuracy of the vertical data related back to a 4 foot contour interval or approximately +/- 2 foot. Utilizing the aerial photogrammetry, cross sections were located at a spacing of approximately 0.5 miles and vertical data extracted along these cross sections. Cross section data was provided in a HEC-2 format and then imported into HEC-RAS

format. No bridge or structure surveys were performed. Bridge data was derived from available as-builts and a visual field check of the basic bridge design elements.

The cross sectional data used in the development of the model, from the Chatfield Reservoir to the Adams/Weld County line, was derived from the various FIS models prepared for this reach. As noted above, the vertical datum used in the creation of the models was adjusted to 1988 NAVD Seal Level Datum. Existing cross sectional data contained in the historic flood insurance study models was adjusted as required to match NAVD 88.

The cross sectional data used in the development of the Cherry Creek and Bear Creek models, from the Cherry and Bear Creek Reservoirs to the confluence with the South Platte River, was derived from HEC2 models prepared in 1995 by the Omaha District of the U.S. Army Corps of Engineers. As noted above, the vertical datum used in the creation of the models was adjusted to 1988 NAVD Seal Level Datum.

The origins, adjustments and locations of the cross sections used in the hydraulic analysis are shown in the plates and tables (Tables 1a – 1c) located in Appendices I-A and I-B at the end of this report.

4. STUDY DISCHARGES.

Water surface profiles were developed based upon discharges computed by the Omaha District of the Army Corps of Engineers specifically for this study. The results of this analysis is included in Appendix H of this report with a summary of the discharges used in developing the water surface profiles shown in Table 2a – 2c) located in Appendix I-B at the end of this report.

5. DEVELOPMENT OF HEC-RAS MODEL.

5.1 Analytical Methods and Model Assumptions.

HEC-RAS version 3.1.2 dated April 2004 was used in calculating the water surface profiles for the South Platte River. HEC-RAS is a steady state backwater model used to calculate water surface elevations for a single discharge regardless of time.

HEC-RAS assumes steady, gradually varied flow in natural or man-made channels. The effect of various obstructions, such as bridges, culverts, and structures, in the channel and flood plain can also be considered. The main input data requirement for HEC-RAS is stream and flood plain geometry in the form of cross sections taken at right angles to the direction of flow. Bridge and culvert data is also included in the input. The standard step method computational procedure is based on the solution of the one-dimensional energy equation and friction loss evaluated with Manning's equation.

5.2 Roughness Coefficients and Bridge Losses.

In the HEC-RAS model reach from the Adams/Weld County lines to the Colorado/Nebraska State line the roughness coefficients for the channel and overbanks were set based on engineering judgment and field examination of the aerial photogrammetry. This information was provided by the Colorado Water Conservation Board for use by the Omaha District of the Army Corps of Engineers in the development of the HEC-RAS model. The South Platte River is a sandy earthen channel with minor irregularities, occasional variations, negligible effects of obstructions, and low vegetation producing a Manning's "n" value of 0.025-0.035. A Manning's "n" value of 0.040-0.060 was used for the over banks based upon a floodplain with grass pastures and/or light/medium brush in summer time. Roughness coefficients for the channel and over banks were correlated with the values listed on pages 112-113 in *Open-Channel Hydraulics* by Chow. Utilizing the aerial photogrammetry variations in Manning's "n" were identified across the section. An "n" value of 0.026 was used within the channel banks, a value of 0.050 and 0.060 was used in areas of brush and trees, depending upon the density of growth, and a value of 0.040 was used for other over bank areas.

The energy modeling method was used for to compute water surface elevations on all bridges in the study. Contraction and expansion coefficients of 0.3 and 0.5 were used for all bridges while contraction and expansion coefficients of 0.1 and 0.3 were used for all other areas. A comprehensive document of the available bridge structure data was provided from the survey contractor and this data was used in the development of the model. Inconsistencies in this document were identified during the field check of the bridges and changes made to the model to reflect these visual inspections. A summary of this survey has been shown in Table 3a located in Appendix I-B at the end of this report.

In the reach from Chatfield Reservoir to the Adams/Weld County lines, the roughness coefficients for the channel and overbanks were based upon what was used in the original FIS model used as the basis for the HEC-RAS modeling in this reach.

Many of the bridges in the original FIS models were represented using the HEC2 Special Bridge routine. In importing these models into HEC-RAS, the geometric parameters of the bridge structures often times do not accurately represent the actual geometric configuration. For this reason a comprehensive cursory bridge inventory was conducted along this reach to assure that the basic bridge parameters used in the model matched those found in the field. This survey noted the type of construction, number of piers and general bridge opening configuration in order to accurately model the bridges within the accuracy parameters of the study scope. In addition new bridges constructed prior to the development of the FIS models were noted and included in the HEC-RAS model. A summary of this survey has been shown in Table 3b located in Appendix I-B at the end of this report. The energy modeling method was used for to compute water surface elevations on all bridges in the study. The contraction and expansion coefficients used in the FIS models were used in this reach of the model.

No changes were made to the Cherry and Bear Creek geometric data used in the development of the HEC-RAS model for these reaches. Manning's "n" values and expansion/contraction coefficients were not altered. Special bridge data originating from the HEC2 models were

modified to accommodate the importing of bridge data into the HEC-RAS model.

5.3 Accuracy Of Model.

A calibrated HEC-RAS model was not required for this analysis, since the purpose of this study is to evaluate and compare proposed design flow scenarios against those of existing conditions. However it is important to realize the factors inherent in the model which affect the results. Following is the methodologies used to assess the accuracy of the reach components of the HEC-RAS model.

South Platte River – Adams/Weld County Line To Colorado/Nebraska State Line: To determine the accuracy of the HEC-RAS model for the reach from the Adams/Weld County lines to the Colorado/Nebraska State lines, comparisons were made between the rating curves generated by the model and those at USGS gaging stations along the river. (See Tables 4a – 4d located in Appendix I-B) The rating curves of the model varied 2 to 4 feet above those of the gaging stations, with an average of approximately 2 feet.

A Manning's "n" value sensitivity analysis was performed to determine if an adjustment to the "n" value could better correlate the rating curves between the model and the gaging stations. Maximum and minimum combinations of Manning's "n" values, that could be anticipated along this reach of the South Platte, were selected and run within the HEC-RAS model. The sensitivity analysis showed that the model was only mildly sensitive to "n" values and that substantial changes to the "n" values would be required to match the gaging station rating curves. Water surface elevations varied approximately 1 foot between minimum and maximum combinations of "n" values (0.025-0.035 channel; 0.040-0.050 over bank). The selected values used in the model fall within the lower third of this band and appear to be reasonable in their use within the model.

Discrepancies that exist between the USGS and the HEC-RAS model rating curves could be attributed to the inherent inaccuracies of the survey data. With a 4 foot contour interval specific elevations could be expected to vary by +/- 2 feet. The sensitivity of this data became apparent by utilizing a digital terrain model (dtm) prepared in 2004 for Weld County. Utilizing the InRoads computer program, an additional HEC-RAS model for Weld County was created utilizing this more detailed dtm. A comparison between the cross sections provided in 1998 with those generated from the "dtm" showed that while the cross sections were the "same" in general topographic configuration, the level of detail provided by the "dtm" exceeded that from the 1998 effort. The analysis of these two models showed water surface elevations fluctuating of 1-2 feet (above and below) between the generated water surface elevations of each model. This analysis is in line with the values shown in Table 5-2 of EM 1110-2-1619 which shows for fair Manning's "n" value reliability and survey data derived from topographic mapping that a standard deviation in the water surface profile of +/- 0.9 feet could be expected.

Also, the minimal geometric representation of the bridge structures in the model could also be a factor impacting the correlation between the USGS and the HEC-RAS model rating curves, since all of the gaging stations are located adjacent to bridges.   The top of road profiles derived from the aerial photographs did not appear to be accurate. Difficulty in deriving such information

from aerial photographs is common and therefore the provided data was modified to approximate the bridge structures.

South Platte River – Chatfield Reservoir To Adams/Weld County Line: The accuracy of the HEC-RAS model for the reach from the Chatfield Reservoir to the Adams/Weld County lines, was assessed by comparing the 100 year water surface profiles generated by the HEC-RAS model and those of the original HEC2 FIS models using the FIS 100 year discharges. Absolute weighted differences in water surface elevations between the original HEC2 models and the newly created HEC-RAS were computed. The differences in these two methodologies range from 0.3 to 0.5 feet. The differences in water surface profiles can be attributed to variations in the computational methodologies between to two programs in dealing with the bridges within the reach and cannot be rectified within the scope of this study. It was felt that the differences noted in the two methodologies was within the accuracy limits required by the study and as such no adjustments were made to the basic variables of the HEC-RAS model to bring it in line with the results from the HEC2 models.

Cherry Creek And Bear Creek: No assessment of the accuracy was performed on the model reaches along the Cherry Creek and Bear Creek reaches due to a lack of data.

5.4 Water Surface Profiles.

Using the HEC-RAS model, baseline and alternatives with project conditions water surface profiles were calculated for the 2-, 10-, 50-, 100- and 500-year flood events and provided for use in the evaluation of the proposed with project alternatives. A comparison was made between the water surface elevations generated between the two proposed alternatives and the baseline conditions. The results of this analysis are shown on Tables 6a – 6e located in Appendix I-B. For the two alternatives reviewed the discharges either remained the same or decreased from those listed for the baseline condition. An exception to this statement relates to a small increase on the South Platte of 100 cfs for the 2-year frequency event from the Baseline scenario to the Alternative scenario reflecting the 5437 pool. This increase reflects a less than 1 percent increase in the discharge and relates back to a less than a 0.1 foot rise and as such has been judged to be statistically insignificant. (See Tables 7a- 7e located in Appendix I-B)

With no increase in discharges and in most cases a decrease in discharges, the water surface profiles of the alternatives remained the same or decreased from those of the baseline conditions for each of the studied events. Isolated increases in the water surface profiles in the range of 0.1 to 0.4 feet for the 100 year frequency event and 0.1 to 0.6 feet for the 500 year frequency event are shown for a very minimal number of cross sections in the model. (Thirteen (13) and eight (8) sections respectively out of a total of over fifteen hundred (1500) sections in the entire model.) These sections are scattered throughout the model at three to four locations along the South Platte alignment and are a result of the impact from the water surface just rising or falling, above or below a change in the channel cross section. This small change in water surface elevation has a disproportionate computational impact upon the water surface elevations at and immediately upstream of this location.

With the small changes in discharges identified between the baseline conditions and the alternatives, the accuracy of the model is challenged to produce statistically comparable water surface elevations. The accuracy of the geometric properties of the section cannot be adjusted to produce comparable results without creating a separate model for each of the events and setting the ineffective flow areas for that scenario to match the unique flow characteristics of that particular discharge. This work is outside the scope of this study and not necessary for the level of detail required by this analysis. From the water surface modeling performed to date for the analyzed flood events, it can be stated that the results show no adverse impacts between the baseline conditions and the proposed alternatives that would require mitigation.

6. SUMMARY

A comprehensive HEC-RAS model was developed for the South Platte, Cherry Creek and Bear Creek. The geometry of the model was derived from topographic mapping, cursory field surveys and historic FIS models. The inherent inaccuracies of the data used in the development of the model made it impossible to create a totally calibrated model. However for the use intended in this study of comparing the impacts associated with different flow scenarios against those of the existing conditions scenario this level of accuracy is sufficient. Utilizing this model, water surface profiles were calculated for the 2-, 10-, 50-, 100- and 500-year flood events for the baseline and proposed alternatives. In all cases the flows generated from the alternative scenarios were equal to or less those of the existing conditions scenario and through the HEC-RAS model it showed no adverse impacts resulting from the proposed alternatives which would need to be mitigated.